Tech-notes

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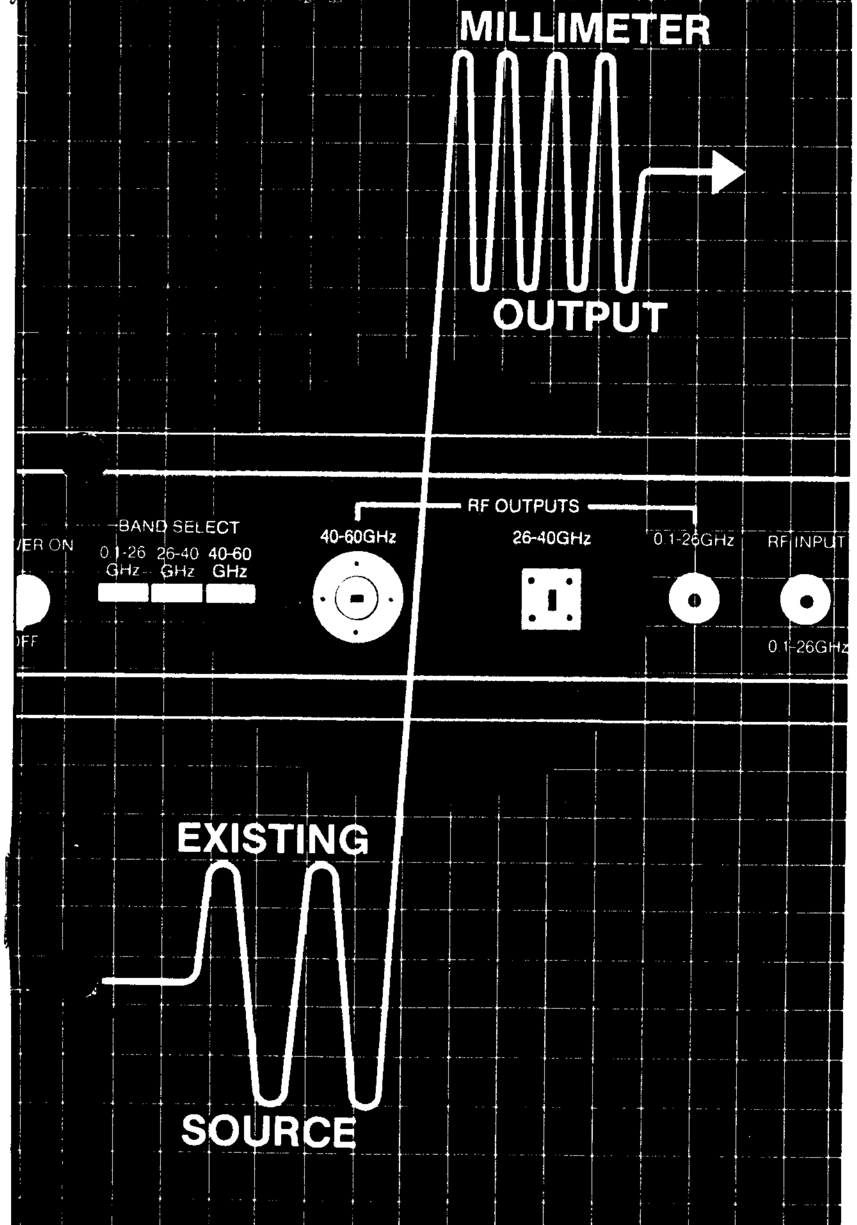
18 to 60 GHz Signal Generation from Existing Sources



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Applications which have been expanding into the 18- to 60-GHz region include communication systems, radars, instrumentation and reconnaissance receivers. As a result of this upward frequency growth, a need has developed for stable, accurate, easily controlled and spectrally pure signal sources above 18 GHz.

Heretofore, the choice of signal generation equipment in the 18- to 60-GHz range and the technical performance obtainable have been limited. Fixed-frequency oscillators have limited use, since only a single frequency is available. To meet broadband signal generation requirements, mechanically tunable oscillators (klystrons and Gunns) and sweepers (backward-wave oscillators, Gunns and Impatts) are used, but for many measurements, the phase noise and frequency stability of these oscillators are not adequate. Phase-locked oscillators are available to provide better stability, phase noise and accuracy, but these tend to be fixed frequency or narrowband (several hundred megahertz or less). Another alternative utilizes a microwave/millimeter-wave frequency counter to lock a millimeter-wave oscillator to the counter's crystal reference. This technique provides broadband phase-lock capability, resulting in improved frequency stability, but requires extra millimeter components and instrumentation to achieve this performance.

Signal generation to 60 GHz may also be achieved by multiplication of a low-frequency source. Currently, there are many 18- and 20-GHz microwave sources in use. Watkins-Johnson Company undertook the project to extend these standard sources to 60 GHz without requiring any modification to the standard source. The result was a series of millimeter wave frequency extenders that extend the frequency range of an 18-GHz source to 40 GHz and a 20-GHz source to 60 GHz. The units are lightweight and compatible with 18-GHz or 20-GHz signal sources that provide 0-dBm output power. The frequency extender amplifies and multiplies this signal, resulting in an output of +3 dBm from 18 to 40 GHz and 0 dBm from 40 to 60 GHz. These units may be used with sweep oscillators, signal generators, and frequency synthesizers to extend their performance into the millimeter frequency range.

Frequency extenders are a cost-effective way to extend 18-GHz (20-GHz) signal sources into the millimeter frequency band. Improved technical performance (i.e., frequency range, stability, phase noise, and modulation) over currently available millimeter sources is provided. This frequency extension may be added at any time with no modifications to the basic source.

The performance of Watkins-Johnson Company's WJ-1204-42, 26- to 60-GHz Frequency Extender, was tested using the Hewlett-Packard 8350A/83595A 10-MHz to 26.5-GHz Sweep Oscillator as the signal source. This system provides frequency coverage from 10 MHz to 60 GHz in either swept or CW mode and is capable of operating manually or automatically.

This article discusses the theory of the frequency multiplication scheme and the performance data obtained utilizing the WJ-1204-42/HP-8350A system.

Frequency Extender Multiplication Technique

Generally, multiplication techniques utilize a low-frequency signal source, typically in C or X band. The output from this source is followed by a harmonic generator providing a comb of frequencies in the 18- to 60-GHz range, which are harmonically related to the frequency of the source. To reject undesired harmonics, the signal is processed through bandpass filters. The multiplier/bandpass-filter combination provides a 20- to 30-dB conversion loss. Input power to the multiplier of better than +10 dBm yields a -10 dBm to -20 dBm signal level in the 18- to 60-GHz frequency range. The output power may be increased by inserting an amplifier after the multiplier, although amplification is difficult and costly at these frequencies.

The noise sidebands on the fundamental are increased by 20 $\log_{10}N$ db, where N = multiplication factor. For multiplication factors such as 2 and 10, the noise sidebands are increased 6 and 20 dB, respectively.

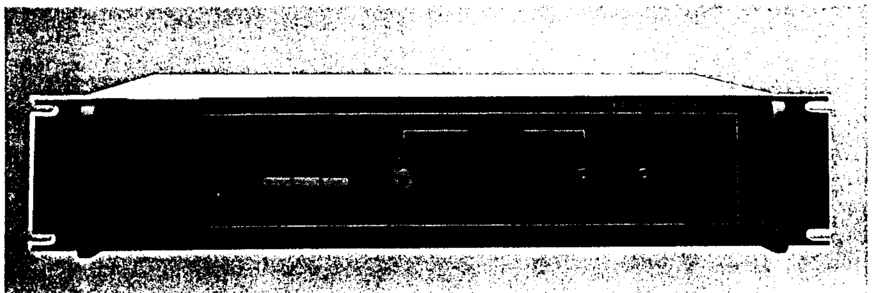
By employing a higher reference frequency, a lower harmonic number can be used for the desired RF output. This will result in a decrease in the conversion loss of the multiplier/filter output and, consequently, a higher output power. The noise sidebands will also be lower, assuming the fundamental signals have identical noise characteristics. Thus, an optimum situation is to use the highest reference frequency possible to maximize both bandwidth and the power out. The best performance over the 18- to 40-GHz range may be obtained from a system utilizing a frequency doubler and a signal source operating within the frequency range of 9 to 20 GHz. Frequency tripling a 13.33- to 20-GHz source provides the best performance over the 40- to 60-GHz range.

WJ-1204-4X Frequency Extender

The WJ-1204-4X Frequency Extender family extends the frequency range of an 8.66- to 20-GHz source to 60 GHz (see Figure 1). The WJ-1204-42 combines the latest advances in GaAs FET amplifier and multiplier technology in a single package. The frequency extender amplifies the 13- to 20-GHz RF input signal (0 dBm) to +17 dBm and inputs this signal to a frequency doubler for 26 to 40 GHz, or to a frequency tripler for 40 to 60 GHz. With typical multiplier conversion losses of 12 dB and 16 dB, respectively, the output is typically +5 dBm for 26 to 40 GHz and +0 dBm for 40 to 60 GHz. The frequency extender provides the full 26- to 60-GHz frequency band coverage when used with a signal source that covers up to 20 GHz. When used with signal sources that cover to 18 GHz, full-frequency band coverage is not provided. For example, when the WJ-1204-42 is driven by an 18-GHz source, 26 to 36 GHz and 40 to 54 GHz will result.

Since the majority of microwave signal sources end at 18 GHz, a modified multiplication scheme is used on other frequency extender models. The WJ-1204-45 is designed for use with 18-GHz sources to provide full 18- to 40-GHz frequency coverage. This is accomplished by applying an 8.66- to 13.333-GHz RF input at 0 dBm and frequency doubling to get 18 to 26 GHz, and frequency tripling to get 26 to 40 GHz. The output power is typically +7 dBm from 18 to 26 GHz and +3 dBm from 26 to 40 GHz.

Rejection of the undesired harmonics to yield typically better than -20 dBc of rejection is accomplished by utilizing the natural waveguide cutoff, an external high-pass filter, and the multiplier's inherent rejection. The high-pass filter is standard in the frequency extender. The full line of frequency extenders and their specifications are shown in Figure 2.



2 to 60 GHz signal source — HP8350/83595 and WJ-1204-42.

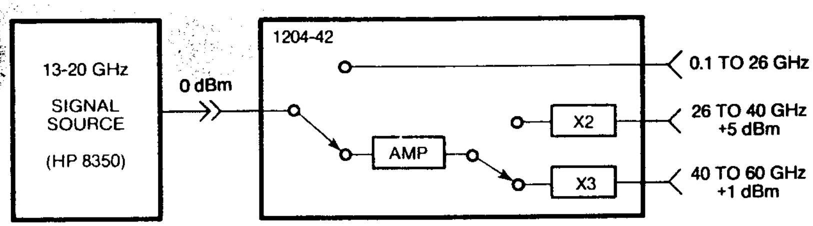


Figure 1. Frequency extender block diagram.

	1204-40	1204-41	1204-42	1204-43	1204-44	1204-45
Output Frequency	26-40GHz	40-60GHz	26-60GHz	18-26GHz	26-40GHz	18-40GHz
Output Power	+3 dBm	0 dBm	0 dBm	+7 dBm	+3 dBm	+3 dBm
Input Frequency	13-20GHz	13.33-20GHz	13-20GHz	9-13GHz	8.66-13.33GHz	8.66-13.33GHz
Input Power	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm
Harmonics	-20 dBc	-20 dBc	-20 dBc	-20 dBc	-20 dBc	-20 dBc
Subharmonics	-20 dBc	-20 dBc	-20 dBc	-20 dBc	-20 dBc	-20 dBc
RF Input Connector	WPM-3 Female (SMA Compatible)	WPM-3 Female (SMA Compatible)	WPM-3 Female (SMA Compatible)	WPM-3 Female (SMA Compatible)	WPM-3 Female (SMA Compatible)	WPM-3 Female (SMA Compatible)
RF Output Connector	WR-28WG UG-599/U	WR-19WG UG-383/U	WR-28WG UG-599/U WR-19WG UG-383/U	WR-42WG UG-595/U	WR-28WG UG-599/U	WR-42WG UG-595/U WR-28WG UG-599/U
[illegible]	10 lbs 4.52 Kg					
[illegible]	19 x 3½ x 14 in. 48 x 9 x 36 cm					
[illegible]	115/230V ± 10% 50-60 Hz 50 Watts					

Operation

One of the important characteristics of the frequency extender system is the convenience and simplicity of its configuration and operation. All that is required to configure the system is connection of the RF output of a source, such as the HP 8350A Sweep Oscillator, to the RF input of the WJ-1204-4X Frequency Extender. The source is then set for the appropriate frequency output, taking into consideration that the frequency extender will multiply this frequency by a factor of two or three, depending on the model. The other source parameter that must be set is the output power. An input power level of 0 dBm is recommended for the WJ-1204-4X; however, a limited range of other levels may be used. Refer to the section on conversion efficiency to determine the appropriate input power level for the desired output power level.

Overview Of Compatible HP And W-J Sources

Signal sources from Hewlett-Packard and Watkins-Johnson Company that have compatible frequency coverage for use with the frequency extenders are shown in Figure 3.

Performance

To evaluate the performance of the frequency extender, an evaluation system was configured using the HP 8350A/83595A and the WJ-1204-42. The areas of performance evaluated are frequency accuracy and stability, out-

		FREQUENCY EXTENDERS					
Output Frequency (0 dBm)		26-40GHz	40-60GHz	26-60GHz	18-26GHz	26-40GHz	18-40GHz
Model		1204-40	1204-41	1204-42	1204-43	1204-44	1204-45
Manufacturer	Model						
Hewlett Packard Signal Generators	620B(11GHz)	—	—	—	18-22	26-33	18-22, 26-33
	626A(10-15GHz)	26-31	40-46.5	26-31, 40-46.5	20-26	30-40	20-26, 30-40
	628A(15-21GHz)	30-40	45-60	30-40, 45-60	—	—	[illegible]
Synthesized Signal Generators	8672A(18GHz)	26-36	40-54	26-36, 40-54	FB	FB	FB
	8673A(26.5GHz)	FB	FB	FB	—	FB	26.5-40
	8684A(12.5GHz)	[illegible]	[illegible]	—	18-25	26-37.5	18-25, 26-37.5
Sweep Oscillators	8620/86260C	34-40	51-60	34-40, 51-60	—	—	[illegible]
	8620/86251 (18.6GHz)	26-37.2	40-55.8	26-37.2, 40-55.8	FB	FB	FB
	8620/86290A/B/C	26-37.2	40-55.8	26-37.2, 40-55.8	FB	FB	FB
	With Option HO8	FB	FB	FB	FB	FB	FB
	8350/83590	FB	FB	FB	FB	FB	FB
	8350/83592	FB	FB	FB	FB	FB	FB
	8350/83594	FB	FB	FB	—	FB	26-40
	8350/83595	FB	FB	FB	—	FB	26-40
Synthesized Sweep Oscillators	8340(26.5)	FB	FB	FB	—	FB	26-40
Watkins-Johnson Synthesized Signal Generator	1204-1(26GHz)	FB	FB	FB	—	FB	26-40
	1250/1251-27 (18GHz)	26-36	40-54	26-36, 40-54	FB	FB	FB
	1291/1251-27	26-36	40-54	26-36, 40-54	FB	FB	FB

FB [illegible]

Figure 3. Compatible signal sources.

put power, conversion efficiency, leveling, output SWR, harmonics and modulation.

The system performance in many areas reflects the performance of the signal source that is used to drive the frequency extender. The Hewlett-Packard 8350A Sweep Oscillator system is a flexible source for use in this application, particularly with its plug-in capability. There are many features associated with the HP 8350A that may be used in this system. Among these features are: FM modulation, external power leveling, programmability, alternate sweep and counted frequency markers.

Frequency Accuracy and Stability

The system frequency parameters are proportional to those of the source. Frequency accuracy and stability are multiplied by a factor of either two or three, depending on whether a doubler or a tripler is used in the frequency extender. The frequency accuracy of the 26.5- to 40-GHz output using the HP 83595A and the frequency extender will be 20 MHz, and the accuracy of the 40-to 60-GHz output will be 30 MHz.

Frequency Enhancements

For maximum stability and frequency accuracy, the low frequency RF output or auxiliary output of the sweeper can be phase locked. This is easily accomplished using the HP 5344S Source Synchronizer. Phase locking the low frequency (13 to 20 GHz) input into the WJ-1204-42 Frequency Extender alleviates the need for millimeter couplers and synchronizers while providing phase-locked performance. Broadband phase locking is significantly easier and more reliable below 20 GHz than at millimeter frequencies.

The frequency accuracy can also be improved with microwave counters. The low frequency RF input to the frequency extender or auxiliary output of the sweeper can be counted when in CW or swept modes using the HP 5343A Microwave Counter. The HP 5343A has the capability (via a two-wire interface) of counting the start, stop or marker frequencies of the HP 8350A while sweeping. The HP 5343A also allows for a multiplier to be entered so that the display reads the millimeter frequency directly.

Output Power

The minimum output power measured across the 26.5- to 40-GHz band is +5 dBm compared with a specification of +3 dBm. The 40- to 60-GHz band has 0 dBm minimum output power, which is the specified performance. There are points along each band (particularly over the first half) where the output power is 2-dB greater than the full-band performance (see Figure 4).

The absolute power measurements were made using the HP 8566 Spectrum Analyzer and an external mixer which down-converts the signal to the frequency range of the HP 8566[1]. The system was automated so that calibration data could be stored and used for error correction. Calibration was done using an HP 8690 BWO to measure the conversion loss of the mixer. Using the signal-identify function of the HP 8566, it is possible to locate the correct harmonic and measure its characteristics. The calibration data was then used to subtract the mixer effects. This technique allows the measurement of the power level of the desired harmonic while removing the other harmonic contributions without filtering.

Conversion Efficiency

Conversion efficiency becomes a consideration in this system since the

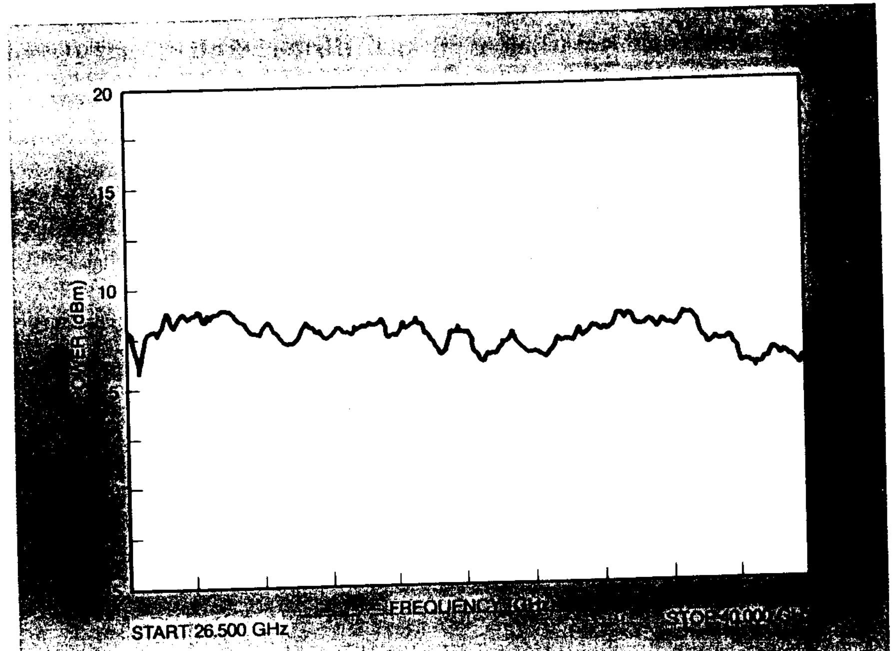


Figure 4A. Maximum output power.

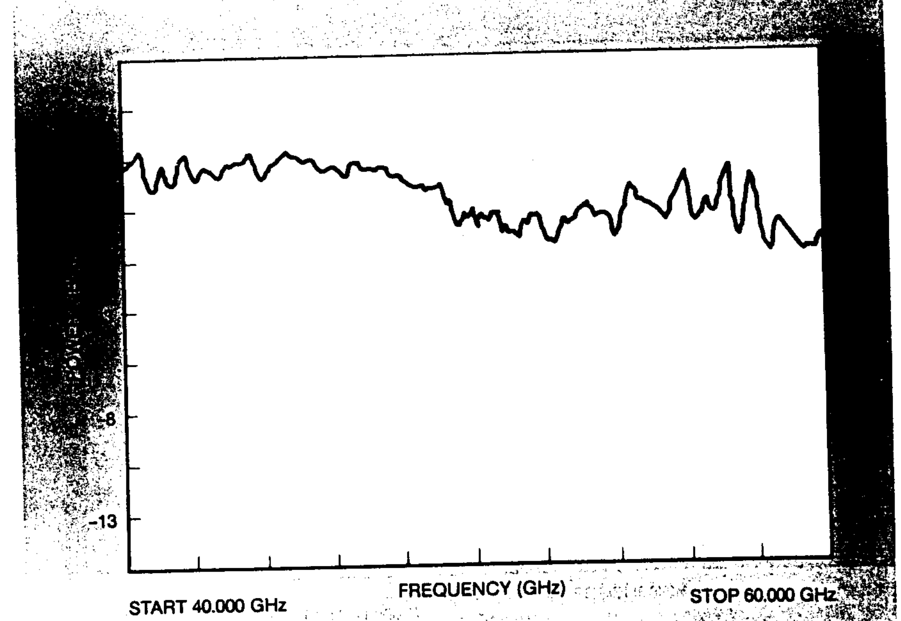


Figure 4B. Maximum output power.

usable operating range is determined by the gain and conversion loss parameters of the amplifier and multipliers in the WJ-1204-42. Figure 5 shows the conversion efficiency of the 26.5- to 40-GHz band and 40- to 60-GHz band over an input power range of -5 dBm to +5 dBm. These plots show that for input power levels greater than 0 dBm (26.5 to 40 GHz) and +2 dBm (40 to 60 GHz), no additional output power results.

The conversion efficiency was measured using the power sweep function of the HP 8350A and the HP 8755C Scalar Network Analyzer. The input power to the WJ-1204-42 was swept from -5 dBm to +5 dBm.

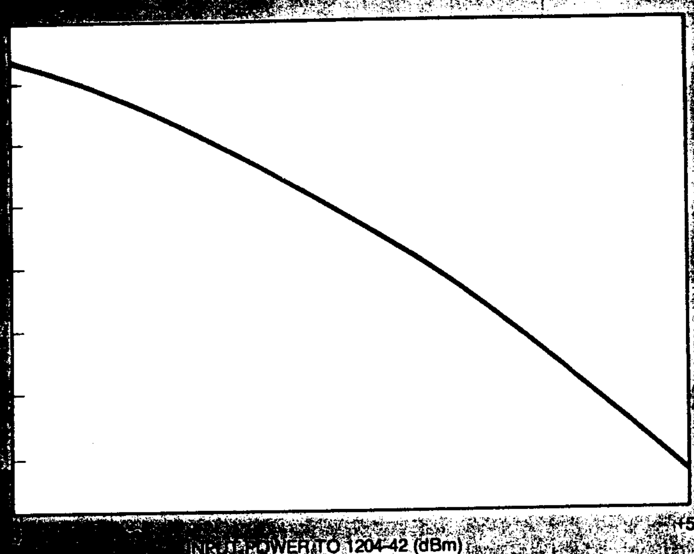
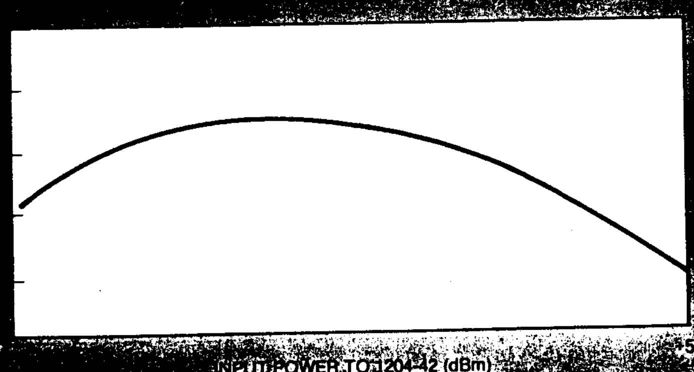


Figure 5A. Conversion efficiency at 33 GHz



Leveling

There are several techniques for improving the output power flatness. Leveling may be done prior to the multiplier input (resulting in unleveled output power) or at the output of the multiplier. Leveling at the multiplier output may be done with a crystal detector.

It is simpler to level at the input to the multiplier since it does not require high-frequency detectors. This technique does not result in leveled output power; however, the power flatness is improved by eliminating the power variations at the input due to cable frequency responses. This technique is capable of producing the maximum power output. Output power variations with 0 dBm leveled input power are ±2.5 dB for both the 26.5- to 40-GHz band and the 40- to 60-GHz band (see Figure 6).

A crystal detector may be used to level at the multiplier output. This technique improves the flatness to ±2 dB when an HP R482 Detector is used in the 26.5-to 40-GHz band, and ±1.5 dB when the Hughes 74323H-1200 Detector is used in the 40- to 60-GHz band. The flatness is limited by the quality of the detector used; therefore, for best results, a high-quality crystal detector should be used. The maximum measured output power with external crystal leveling ws reduced to +4 dBm from +5 dBm (26.5 to 40 GHz) and to -3.5 dBm from 0 dBm (40 to 60 GHz) (see Figure 7).

SWR

The source match at the output of the WJ-1204-42 was measured under three conditions: 1) leveling at the input to the frequency extender, 2) leveling at the input to the frequency extender and an isolator at the output, 3) crystal detector leveling at the output of the frequency extender. The last two methods improve the SWR. These results are tabulated below.

SWR OF WJ-1204-42 OUTPUT

Band	Crystal Leveling at Frequency Extender Input w/o Isolator	Crystal Leveling at Frequency Extender Input w/Isolator	External Crystal Detector Leveling
26.5 to 40 GHz	2:1	1.5:1	1.2:1
40 to 60 GHz	2:1	1.5:1	1.5:1

Harmonics

The spurious signal content of a source is an important consideration in applications that deal with frequency-selective devices. Since this technique uses multipliers, harmonic and subharmonic signals are generated. These undesired signals are a minimum of 9 GHz removed from the carrier. Since most systems that they would drive are much narrower in bandwidth, an effective greater suppression of the undesired signals would result when used in the system. These signals were identified and measured using the same measurement system utilized to measure maximum power output.

26.5 to 40 GHz: This band is generated on the WJ-1204-42 by doubling 13.25 to 20 GHz. The harmonic products from this doubler are plotted in Figure 8A. The output will not contain any 13.25 to 20-GHz feedthrough because this signal is cut off by the waveguide. However, the 3/2 harmonic is of interest as it falls in band at 39.75 GHz, and various modes may be present out of band. Figure 9 shows the 3/2 harmonic to be at least 20 dB below f_0.

40 to 60 GHz: This band is generated on the WJ-1204-42 by tripling 13.33 to 20 GHz. The harmonic products are charted in Figure 8B. As before, the output will not contain any 13.33 to 20-GHz feedthrough because this signal is cut off by the waveguide. Part of the 2/3 harmonic is also cut off; however,

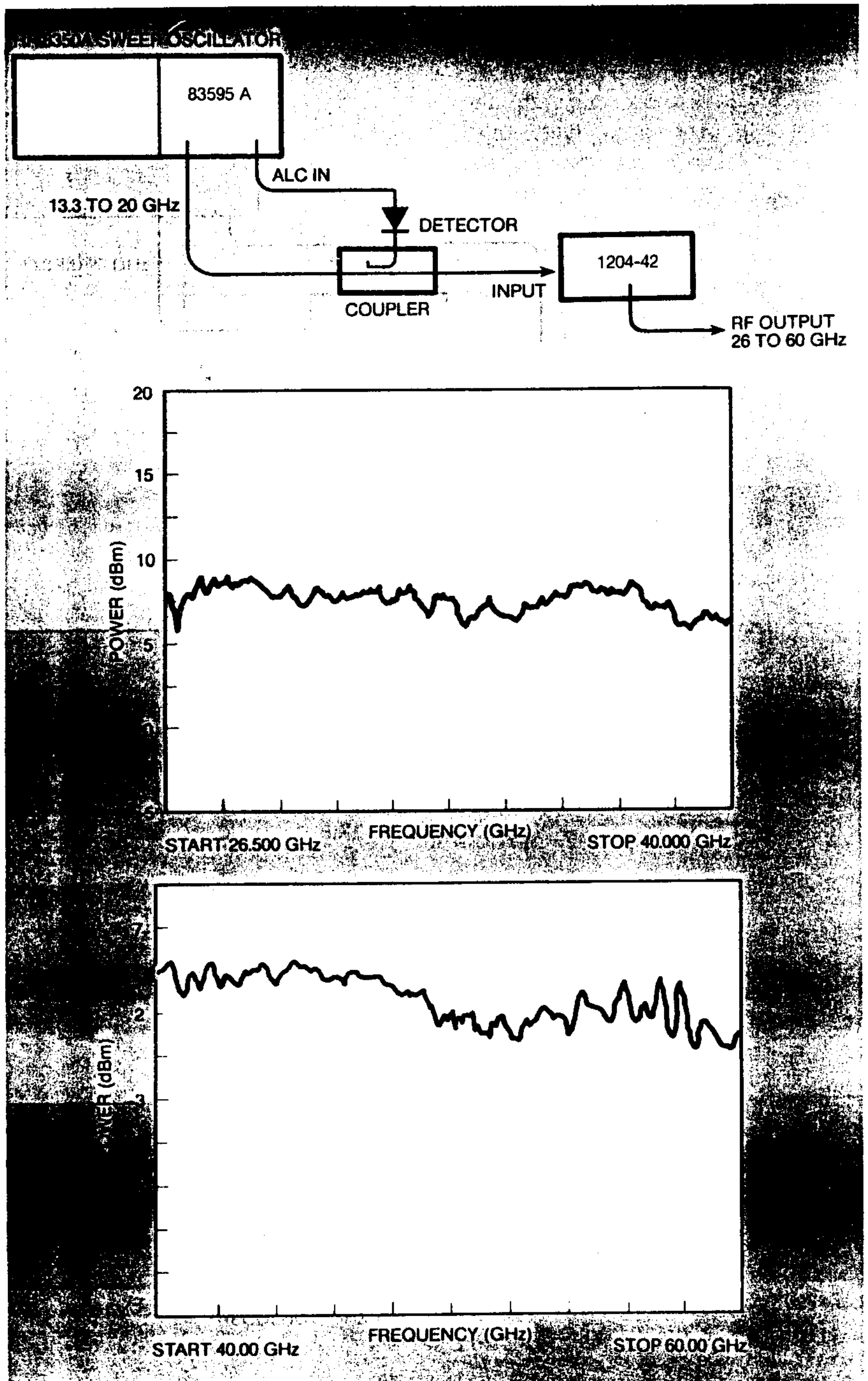


Figure 6. Maximum output power with externally leveled input power.

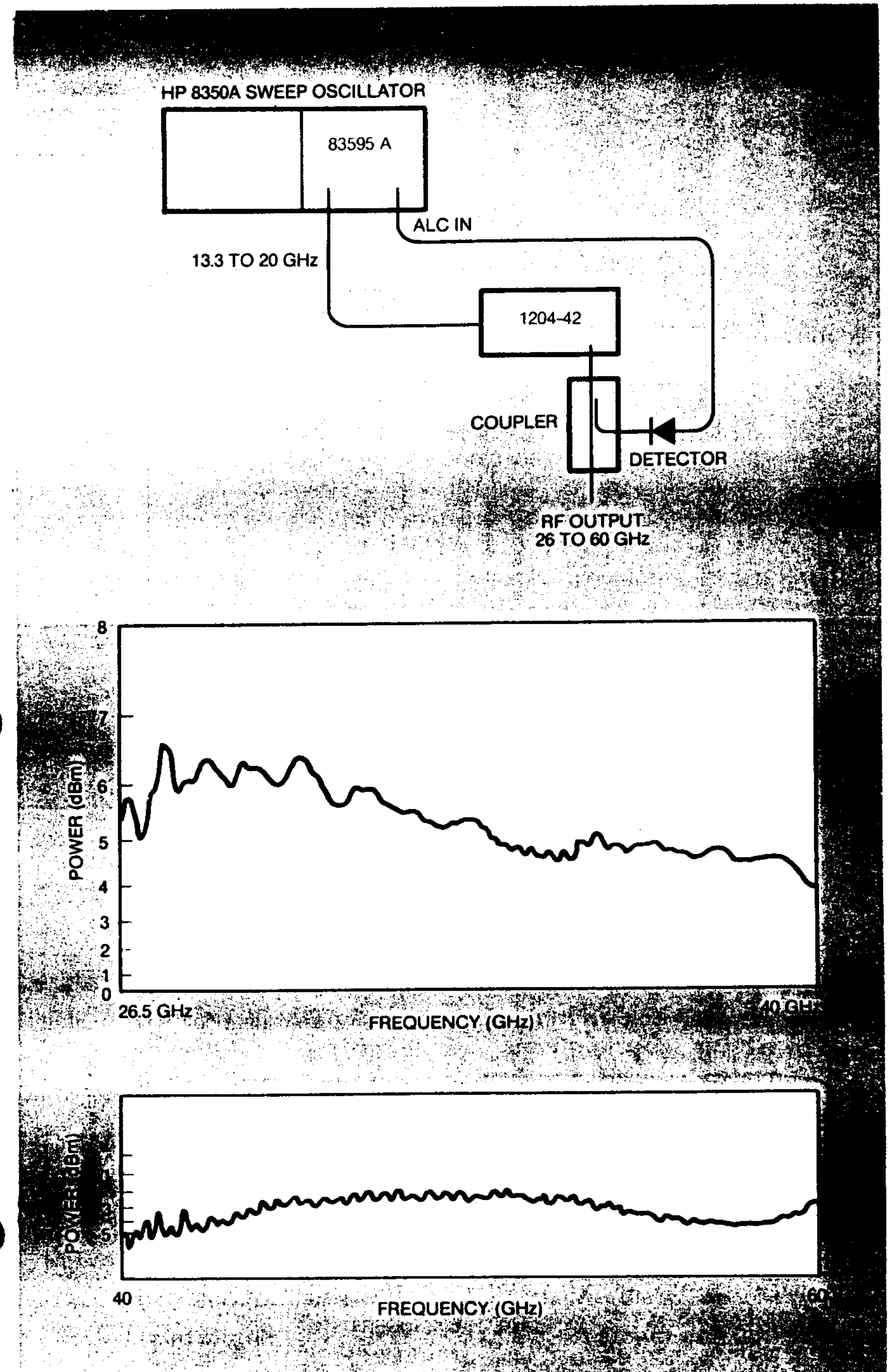


Figure 7. Externally leveled output power.

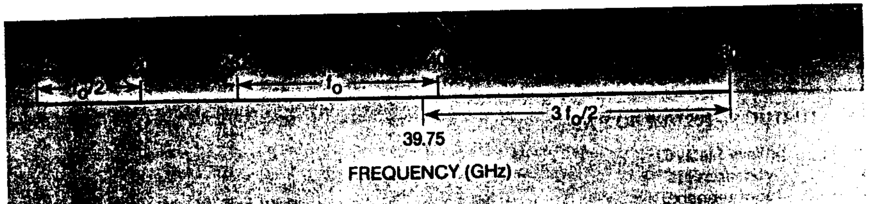


Figure 8A. 26.5 to 40 GHz harmonic products.

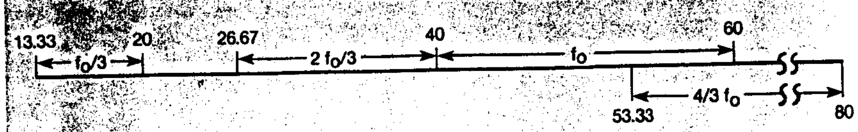


Figure 8B. 40 to 60 GHz harmonic products.

at 31.3 GHz the 2/3 harmonic falls into the waveguide band. Portions of the frequency range (as seen in Figure 10) contain 2/3 harmonic signals as high as 13 dB below f_0. To eliminate this signal, a high-pass filter may be used to reject the 2/3 harmonic (see Figure 11). The 4/3 harmonic is also of interest because modes of it may be present; Figure 12 shows that this harmonic lies about 20 dB below f_0.

Modulation

With this system, it is possible to modulate the RF plug-in for a modulated millimeter output from the WJ-1204-42. The following forms of modulation were evaluated:

FM Modulation: FM modulation may be input to the sweep oscillator and the corresponding millimeter output will be modulated with an FM deviation two or three times (depending on whether a doubler or tripler is used) the modulation input at the same rate. This causes the modulation index (m) to be scaled by the multiplication factor.

AM Modulation: Amplitude modulation through the sweep oscillator into the frequency extender is distorted due to the nonlinear conversion efficiency of the WJ-1204-42.

Pulse/Square-Wave Modulation: Various pulse trains were input to the HP 83595A, including a 27.8-kHz square-wave which is required for compatibility with the HP 8755C Scalar Network Analyzer. The resultant output had no degradation of the rise and fall time. The output of the WJ-1204-42 showed no wave shape distortion in pulse or square-wave modulation and improved the ON/OFF ratio to 80 dB. This is caused by the additional isolation provided by the frequency multiplier when it is turned off by low input power. This performance is superior to that obtainable by modulating in the 26- to 60-GHz range.

Synthesizer Millimeter Performance

The frequency extender may also be used with frequency synthesizers to extend the high-frequency accuracy and low phase noise in the millimeter range. Other performance factors should be similar to those obtained

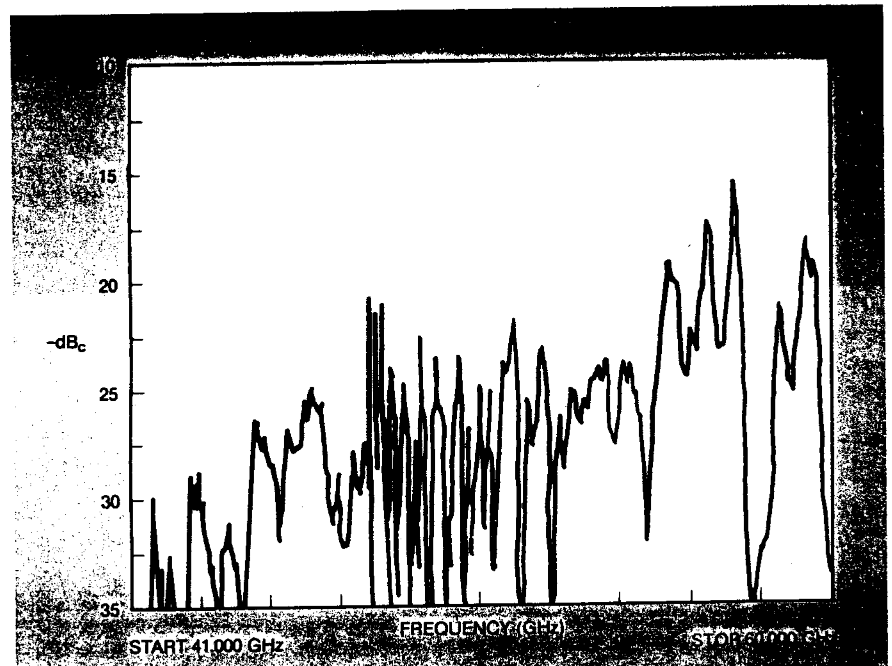


Figure 9. 26.5 to 40 GHz 3/2 f_o harmonic.

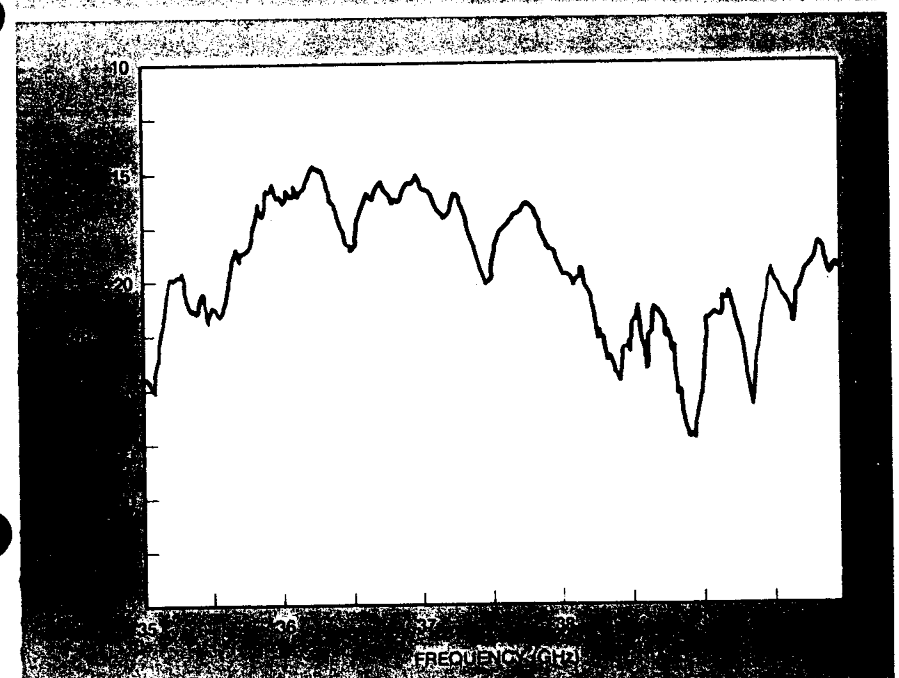


Figure 10. 40 to 60 GHz 2/3 f_o harmonic.

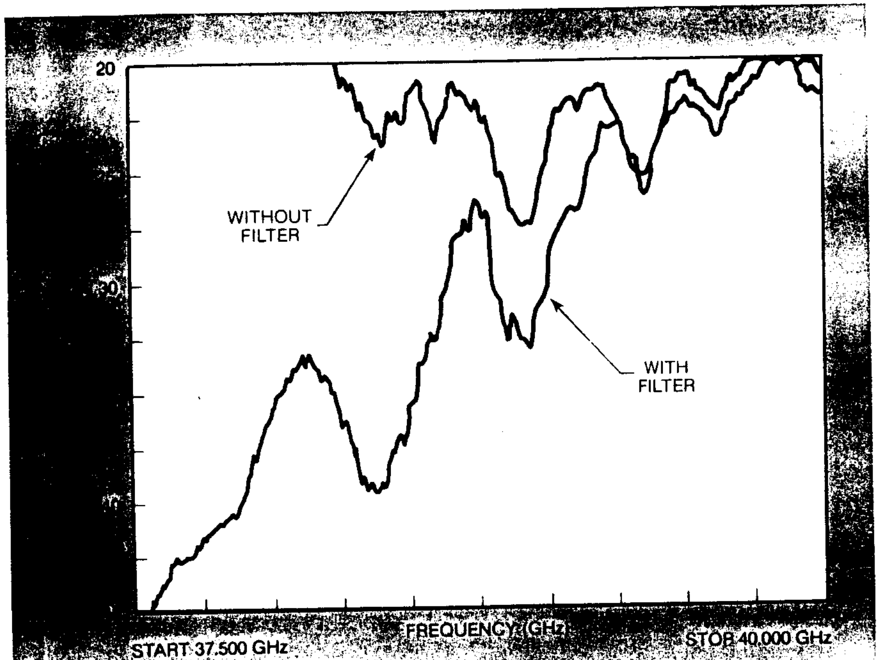


Figure 11. 40 to 60 GHz 2/3 f_o harmonic with high-pass filter.

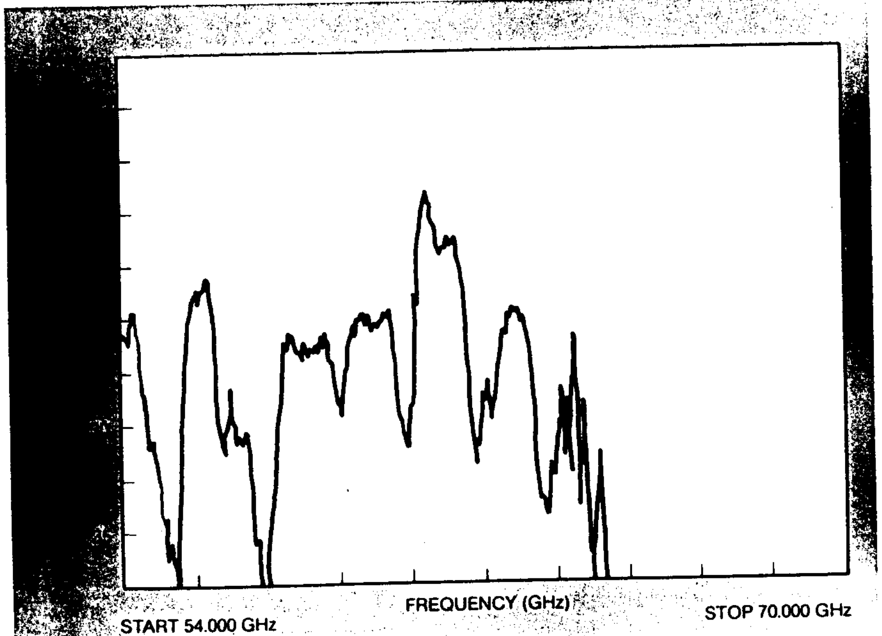


Figure 12. 40 to 60 GHz 4/3 f_o harmonic.

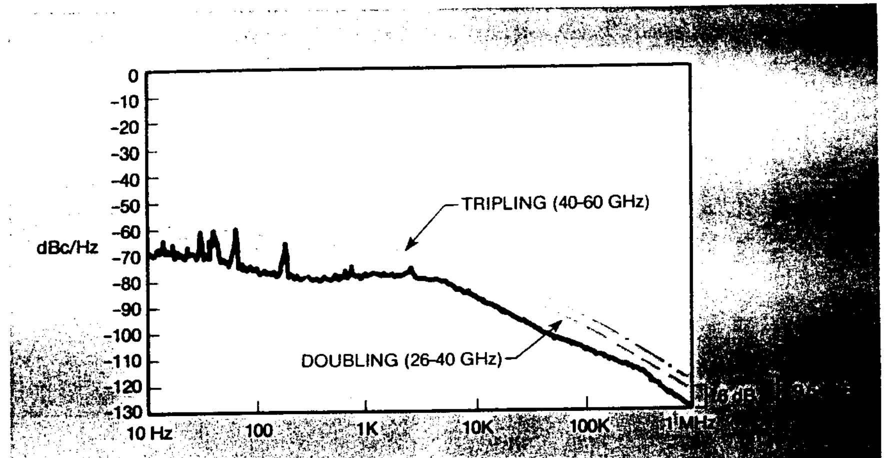


Figure 13. HP 8340A single-sideband phase noise.

with the HP 8350A. The noise sidebands on the multiplied output will be increased by 20 $\log_{10}$N, where N is the multiplication factor. Within 10 MHz of the carrier, the single-sideband phase noise is degraded by approximately the theoretical, which is 6 dB for frequency doubling and 9.54 dB for frequency tripling. Figure 13 shows the input phase noise of the HP 8340A, which could drive the frequency extender and the resultant output when frequency doubled (26-40 GHz) or frequency tripled (40-60 GHz).

Conclusion

With frequency extenders, the performance features of sweep oscillators, signal generators or frequency synthesizers are conveniently translated to millimeter frequencies. This technique yields better performance than fundamental oscillators in this frequency range and has good output power for solid-state millimeter sources. Sweep oscillator or signal generator system performance may be enhanced by phase locking the sweep-oscillator/signal-generator output or auxiliary output; or by using low-frequency counter feedback. The phase noise performance of the synthesizer/frequency-extender combination is typically superior to other available millimeter phase-locked sources. These systems may be fully automated, which provides for convenient calibration and error correction. Frequency extenders are a cost-effective way to extend 18-GHz (20-GHz) sources into the millimeter band.

References

1. Hewlett Packard Product Note 8566-1.
2. Hewlett Packard Application Note 183, "High Frequency Swept Measurements."
3. "18-40 GHz Broadband Frequency Synthesizer Techniques," R.S. Napier and C.E. Foster, Watkins-Johnson Company.

Authors:

Richard S. Napier

Mr. Napier is presently Head of the Synthesizer Equipment Section within the Test Systems Department. His current responsibilities include general management and technical duties. Among his general management duties are the responsibility/authority/accountability for section sales/profit-loss, coordinating and scheduling the manpower and material requirements, assessment of the general business climate, generation of short and long term goals consistent with the desired business growth, and general sales support as required to expand sales, product base, and market. His technical responsibilities include: design, development, and management of commercial microwave frequency synthesizers and related products covering 0.1 to 60 GHz.

He was previously involved as a company program manager on the WJ-1204 Synthesized Signal Generator. He was project/design engineer for the WJ-1221-23 Radar Exciter Simulation System which provided frequency stability, high output power, low level broadband AM/FM, pulse modulation, and low AM/FM noise. Other responsibilities have included synthesizer system sales support and customer interface as acting Applications Engineer.

Mr. Napier received a B.S.E.E. from West Virginia University, and an M.S.E.E. from Stanford University. He is a member of Tau Beta Pi, Eta Kappa Nu, CSPE, NSPE, Association of Old Crows, a 1981 biographer of "Who's Who in the West" (Marquis Publications), a 1980 biographer of "Who's Who in Technology Today," and a Planning Commissioner for the City of Sunnyvale, California.

Judi Cowell

Judi Cowell is presently a product marketing engineer at Hewlett-Packard. She is responsible for applications dealing with the HP 8350A Microwave Sweep Oscillator. She has been involved with millimeter frequency extension of the HP 8350A, phase-noise measurements of phase-locked sweep oscillators, and configuration of two-tone sweep oscillators.

Judi Cowell received a B.S.E.E. with high honors from the University of Florida, and is currently pursuing an M.S.E.E. from Stanford. She is a member of Tau Beta Pi, Eta Kappa Nu and I.E.E.E.